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The Yield Curve Slope and Monetary Policy Innovations

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Abstract

We separate changes of the federal funds rate into two components; one reflects the Fed's superior forecasts about the state of the economy and the other component reflects the Fed's reaction to the public's forecast about the state of the economy. Romer and Romer (2000) found that the Fed reveals information about inflation when it tightens monetary policy. Their research has implications for measuring monetary policy as well. When the Fed raises short-term interest rates it leads to some combination of increased inflationary expectations and an increased real rate. In this paper we estimate a structural VAR that allows us to separate out (identify) components of federal funds changes that are due to inflationary expectations (thus neutral) and that part which is contractionary. Our measure of monetary policy is the part of federal funds changes that exclude the Fed's revelation of its asymmetric information about future inflation.

Keywords
Monetary policy, yield curve, inflation, price puzzle

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Comments
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Contents

1. Introduction

In this paper, we separate changes of the federal funds rate into two components; one reflects the Fed's superior forecasts about the state of the economy and the other component reflects the Fed's reaction to the public's forecast about the state of the economy. We start with the premise that the Fed has asymmetric information about inflation (as well as real growth.) This premise is inspired by the work of Romer and Romer (2000) who found that the Fed reveals information about inflation when it tightens monetary policy. Their aim was to explain the puzzle that long-term interest rates respond positively to Fed rate hikes. They found "that between half and all of the increase in long-term rates following a monetary contraction may be due to the revelation of Federal Reserve information."

Romer and Romer's (2000) work has implications for measuring monetary policy as well. When the Fed raises short-term interest rates it leads to some combination of increased inflationary expectations and an increased real rate. To the extent that it is an increase in inflationary expectations, the rate hike is neutral. To the extent that it is an increase in the real rate, it is contractionary. In this paper we estimate a structural VAR that allows us to separate out (identify) these two components of federal funds changes. Our measure of monetary policy is the part of federal funds changes that result in a change in the real interest rate. In other words, it is the part of federal funds changes that exclude the Fed's revelation of its asymmetric information about future inflation.

In addition to developing a measure of monetary policy, which eliminates the Fed's information revelation, we also address the so-called "price puzzle." The price puzzle, a feature of most VAR based macro models, is that the price level (or inflation) rises in response to a monetary tightening. This puzzle was first identified by Sims (1992) and subsequent work (Leeper, Sims and Zha (1996)) has shown that it is robust to a wide variety of model specifications. Two solutions to this puzzle have been proposed. Some researchers have added a measure of commodity prices to the VAR along with inflation (Eichenbaum (1992), Sims (1992), Sims and Zha (1994), Christiano, Eichenbaum and Evans (1996)). The price puzzle disappears when commodity prices are added to the VAR. Recently, a second solution has been proposed. Barth and Ramey (2001) show that the rise in prices could be the result of an increase in costs that are a result from monetary policy tightening. As short-term rates rise, borrowing costs rise and firms increase the price of their product to (somewhat) compensate for the increased costs.

In this paper we propose an alternative explanation. When the Fed raises short-term interest rates it reveals some private information that it has about the future path of inflation. Market participants see this as an indication that inflation will rise in the future and thus tack on an inflation premium. To the extent that the Fed's forecast is correct, some portion of the Fed's rate hike will be followed by an increase in the inflation rate.

Of course not all increases in the federal funds rate reveal private information and it is likely the case that a given rise in the federal funds rate partly reveals private information and partly reflects a true tightening of monetary policy. Thus, we identify a structural VAR that allows us to separate out the changes in monetary policy that reveal information about inflation from changes in monetary policy that are something else.

This paper is organized as follows. Section 2 briefly reviews the literature on identifying monetary policy. Section 3 looks at the relationship between changes in the yield curve slope and changes in long and short-term interest rates. Section 4 describes the intuition behind our identifying assumptions. Section 5 describes the empirical method and the identifying restrictions. Section 6 presents the results and Section 7 concludes.

2. Measuring Monetary Policy

Romer and Romer (2000) showed that federal funds innovations are comprised of two parts—one part is a signal to market participants about the Fed's superior inflation forecasts. The other part is the actual tightening or loosening of monetary policy. Our goal is to examine the effects of policy on the economy once changes in the federal funds rate have been purged of the part that signals the Fed's inflation forecasts.

There is a vast literature on the topic of measuring monetary policy. Anderson and Jordan (1968) and Sims (1972) are two early examples of research that used monetary aggregates to measure monetary policy. The problem with using monetary aggregates, however, is that they represent endogenous (demand determined) movements as well as exogenous (supply determined) movements.

Bernanke and Blinder (1992) argue that the federal funds rate is an appropriate measure of the stance of monetary policy. They show that prior to 1979 the Fed responded nearly completely elastically at the target federal funds rate. During the so-called monetarist experiment (1979-1982) they find that the supply of non-borrowed reserves had a positive but small upward slope. They conclude that even after 1987 the federal funds rate is a better measure of monetary policy because it contains less endogenous movements than monetary aggregates.

Romer and Romer (1989) and Boschen and Mills (1991) construct subjective measures of monetary policy based on their readings of Federal Open Market Committee meetings minutes. As Bernanke and Mihov (1998) explain in their review of this literature, the advantage to the subjective narrative approach is that it likely avoids some of the endogeneity problems associated with using monetary aggregates. But the disadvantage of the Romers' 1989 work is that is does not provide data on periods when monetary policy was expansionary (they only focus on contractionary monetary policy) and they do not measure the degree to which monetary policy is contractionary. Boschen and Mills get around this problem somewhat because they classify policy changes as “mild,” or “strong.” But of course the biggest drawback of these subjective approaches is that they are, well—subjective.

Christiano and Eichenbaum (1992) measure the stance of monetary policy by the quantity of nonborrowed reserves. But as pointed out by Bernanke and Mihov, this measure of monetary policy is only relevant if the Fed operates a strict nonborrowed reserves target. Thus, the Christiano and Eichenbaum identification method assumes a strict nonborrowed reserves target while the Bernanke and Blinder measure of monetary policy assumes a strict federal funds interest rate target. But to the extent that the Fed uses a combination of non-borrowed reserves targeting and federal funds interest rate targeting, both measures will be inaccurate measures of the stance of monetary policy.

Works by Strongin (1995) and Bernanke and Mihov (1998) present measures of monetary policy that can accommodate variations in the Fed’s monetary policy operating procedure. Strongin’s method nests the two extreme assumptions of exogenous non borrowed reserves (Christiano and Eichenbaum) and infinitely elastic non borrowed reserves (Bernanke and Blinder). Bernanke and Mihov’s method nests these operating procedures as well as other operating procedures such as borrowed reserves targeting. Thus, Bernanke and Mihov present the most general and flexible method for measuring the stance of monetary policy. The importance of Bernanke and Mihov’s work for our present study is that they find that the federal funds rate is the best indicator of monetary policy prior to 1979 and again after late 1987 when Alan Greenspan became chairman of the Federal Reserve. During the early to mid-1980s the Fed appeared to target non-borrowed reserves and therefore the approach by Strongin for measuring monetary policy appears to be best for samples including that period.

In a recent paper Romer and Romer (2004) derive a measure of monetary policy shocks that removes “endogenous and anticipatory” Fed responses from the federal funds interest rate. They do this by removing from the federal funds interest rate the Fed’s typical responses to future economic developments based on their published Greenbook forecasts. Using their new measure they find that monetary policy has a stronger and faster effect on output than the federal funds interest rate. Their new measure of monetary policy also does not produce the “price puzzle.”

Our approach, aim and results differ from Romer and Romer (2004). Their aim is to remove the *Fed’s* anticipations of the economy from the change in the federal funds rate. Those anticipations are measured by the Fed’s Greenbook forecasts and other qualitative information from the Greenbook and other internal Fed documents. But it is important to note that the Fed’s forecasts and qualitative anticipations of the economy are not available to the public (until after a five-year lag). Thus, with each change in the federal fund rate target, the public must form an expectation of which part is a reaction to the economy and which part is a revelation of the Fed’s inflation forecast. While Romer and Romer‘s (2004) measure of monetary policy captures the Fed’s intended monetary policy actions, our measure captures the public’s perception of the Fed’s intended monetary policy actions.

3. The Yield Curve Slope and Long and Short-Term Interest Rates

In this section we look at the data on the yield curve slope and interest rates. Our goal is to see whether there is a general tendency for long and short-term rates to either rise or fall when the slope of the yield curve steepens. These data will help us to determine the extent to which changes in the yield curve slope indicate the direction of monetary policy.

Researchers typically associate an upward tilt of the yield curve with an easing of monetary policy—short-term rates fall and long-term rates rise. Symmetrically, a downward tilt of the yield curve is usually associated with a tightening of monetary policy as short-term interest rates rise and long-term interest rates fall. In this section we look at whether these associations are born out by the data.

Our measure of long-term interest rates is the yield on the 10-year Treasury bond. Our measure of short-term interest rates is the yield on the 3-month T-bill. The difference between the two is defined as the yield curve. The federal funds rate is the monthly average of daily values. Our data are monthly from 1957 through 2003 although we consider various sub-samples as well.

Figure 1 shows the correlations between changes in long-term rates and changes in the yield curve slope for the full data sample (1957-2003, monthly omitting the October 1979 through December 1986 period) and various sub-samples. For the full sample (upper left hand panel) and the pre-Greenspan sub-samples (upper right, lower left panels) there appears to be very little relationship between the change in the yield curve slope and changes in long-term rates. In other words, when the yield curve steepens, long-term interest rates do not appear to systematically rise or fall. But in the Greenspan sample (lower right panel) increases in the yield curve slope are associated with increases in long-term rates and decreases in the yield curve slope are associated with decreases in long-term interest rates. These results seem to suggest that during the Greenspan era, the yield curve tilts more than it shifts (relative to the non-Greenspan eras).

Figure 2 shows the relationship between changes in the yield curve slope and changes in short-term interest rates. In the full sample and the pre-Greenspan samples, an increase in the yield curve slope is associated with a decline in short-term interest rates and a decrease in the yield curve slope is associated with an increase in short-term interest rates. During the

Greenspan era, however, the association is negative but less pronounced. Figure 3 shows a similar pattern for the federal funds rate (changes in the federal funds rate closely match changes in the 3-month T-bill rate).

Taken together, these three sets of correlations appear to indicate that under Greenspan the yield curve tilts more than it shifts (Figure 1) but those tilts are not strongly associated with changes in short-term interest rates. If one equates changes in short-term interest rates with Fed policy (as in Bernanke and Mihov) then Figures 2 and 3 suggest that Fed policy is less associated with changes in the yield curve slope during the Greenpsan era than in previous time periods.

4. The yield curve slope and monetary policy

Timothy Cook and Thomas Hahn (1989) found that when the Federal Reserves raises short-term interest rates, long-term interest rates typically rise as well. Romer and Romer (2000) interpret this as evidence that when the Federal Reserve raises short-term interest rates it reveals private information about future inflation and that future inflation gets built into interest rates all along the yield curve. Thus, the expectation of inflation held by the Fed ($\pi^{e,Fed}$) equals the public's expectation of inflation (π^{e}) plus the superior information about inflation (ε) that the Fed possesses:

$$\pi^{e,Fed} = \pi^{e} + \varepsilon \tag{1.1}$$

Romer and Romer contend that changes in the fed funds rate (at least partly) reveal information about ε. In this section we look at whether ε can be identified by distinguishing between shifts in the yield curve and tilts in the slope of the yield curve. We argue that changes in the federal funds rate associated with shifts in the yield curve represent the revelation of the Fed's superior information about future inflation (ε). Changes in the yield curve slope (tilts in the yield curve) represent the Fed's reaction to the public's expectation of inflation.

To illustrate this hypothesis, we consider a simplified world in which there are one period bonds (subscript S) and two period bonds (subscript L) or short-term and long-term bonds. The the yield curve slope is:

$$slope = i_L - i_S \tag{1.2}$$

Using the Fisher relation and assuming a term premium, we can rewrite this as:

$$slope = \left(prem + rr_L - rr_S \right) + \left(\pi_L^e - \pi_S^e \right) \tag{1.3}$$

Where *rr* denotes the real rate and *prem* is the term premium. In the empirical section that follows we decompose changes in the federal funds rate (i_S) into two components: a component that leaves the *slope* of the yield curve unchanged (the shift component) and a component that alters the slope of the yield curve (the tilt component). For a change in the fed funds rate to leave the slope of the yield curve unchanged, it follows from equation 1.3 that:

$$\Delta\, prem + \Delta\, rr_L - \Delta rr_S = \Delta\, \pi_S^e - \Delta\, \pi_L^e \tag{1.4}$$

The diagonal elements of Table 1 show the cases in which this equation will hold. The middle cell represents the case where the terms on both sides of the equal sign are zero. The (3,3) element is the case where they are positive and of equal value and the (1,1) element is the case where they are negative and of equal value.

We now examine these three cases and lay out the conditions under which a change in the federal funds rate that leaves the slope of the yield curve unchanged can be interpreted as the information revelation component of monetary policy. It is this component that we wish to purge from changes in the federal funds rate in order to isolate the part of monetary policy that represents changes in the real short-term interest rate.

Case 1:

$$\Delta prem + \Delta rr_L - \Delta rr_S > 0 \quad and \quad \Delta\pi_S^e - \Delta\pi_L^e > 0 \tag{1.5}$$

In this case, in order for an increase in the federal funds rate to leave the slope of the yield curve unchanged, the increase in both of these elements would have to be equal. In our empirical application we use the 10-year bond yield as the long-term interest rate. Thus, we suggest that if monetary policy is neutral in the long run, an increase in the federal funds rate which is comprised of some combination of an increase in the real short-term rate (Δrr_S) and short-term expected inflation ($\Delta\pi_S{}^e$) will leave the long-term real interest rate unchanged ($\Delta rr_L = 0$). Assuming this condition holds, an unchanging yield curve slope would require that the term premium rise by more than the short-term real interest rate. If the term premium does not rise by more than the short-term interest rate then we can eliminate this case as a possible explanation for an unchanging yield curve in response to an increase in the federal funds rate. In other words, if an increase in the federal funds rate causes the short-term real rate to rise, the yield curve is likely to tilt rather than shift in response as long as the term premium does not rise by more than the increase in the short-term real rate.

Case 2:

$$\Delta prem + \Delta rr_L - \Delta rr_S = 0 \quad and \quad \Delta \pi_S^e - \Delta \pi_L^e = 0 \tag{1.6}$$

We consider two sub-cases here. The first sub-case is where the increase in the federal funds rate does not reveal any information about short-term or long-term expected inflation ($\Delta\pi_S^e = \Delta\pi_L^e = 0$). In this case the increase in the short-term real interest rate would have to be matched by an equal increase in the long-term real interest rate plus the term premium. Again, assuming that the real long-term interest rate is not affected by current monetary policy ($\Delta rr_L = 0$) this would require that the term premium increase by the same amount as the short-term real interest rate in order to keep the slope of the yield curve unchanged. If this is unlikely to hold then once again an increase in the federal funds interest rate that is accompanied by an increase in the short-term real interest rate will lead to a tilt rather than a shift in the yield curve slope.

In the second sub-case, long and short-term expected inflation rise by the exact same amount ($\Delta\pi_S^e = \Delta\pi_L^e > 0$). If this is accompanied by an increase in the short-term real interest rate then it must once again be the case that the term premium rises by the same amount. But if we can rule out the equality of these two changes then we can rule out any increase in the short-term real interest rate and this case represents pure information revelation on the part of the Federal Reserve. Short-term and long-term expected inflation rise by the same amount and the short-term and long-term real interest rates remain unchanged.

Case 3:

$$\Delta prem + \Delta rr_L - \Delta rr_S < 0 \quad and \quad \Delta \pi_S^e - \Delta \pi_L^e < 0 \tag{1.7}$$

In this case, the increase in the federal funds rate causes the short-term real interest to rise by more than the term premium (again we assume that $\Delta rr_L = 0$). While this is plausible, this case also requires that long-term expected inflation rise by more than short-term expected inflation. But if the short-term real interest rate is rising, then the long-term interest rate will likely rise by less than the short-term expected inflation rate (or, more likely, it will fall).

Suppose for example that the federal funds rate rises by 50 basis points and 25 basis points of that is a real rate increase and the other 25 basis points is information revelation. In order to keep the slope of the yield curve unchanged long-term expected inflation would have to increase by at least half a percent (more than a half a percent if short-term expected inflation is also rising). This seems unlikely because it suggests that a revelation by the Fed that inflation is 25 basis points higher than previously expected will cause long-term expected inflation to rise by more than 25 basis points. Because this is an unlikely response of expected inflation we rule this out as a possible explanation for shifts in the yield curve slope and conclude that changes in the short-term real interest rate will cause a tilt rather than a shift in the yield curve in this case.

In sum, if the term premium increases by less than the increase in the short-term real interest rate and if long-term expected inflation responds less than short-term expected inflation to an increase in the short-term real interest rate then shifts in the yield curve reveal information about future inflation and tilts in the yield curve represent changes in the short-term real interest rate. Our goal is to separate out these two types of monetary policy changes. We expect the first type of change—the “inflation revealing” change in monetary policy—to elicit a positive inflation response in a VAR, the “price puzzle.” We expect a monetary tightening that flattens the slope of the yield curve to cause output growth and inflation to decline.

5. Identifying Monetary Policy in a VAR

We use two structural VARs to identify and analyze monetary policy: first with a three variable system and then a four variable system. In addition, we discuss the evaluation and design criteria used in developing the empirical models.

Monetary Policy in the Structural VAR System

We begin by estimating a benchmark VAR that contains three variables: the federal funds interest rate, inflation and real output growth. This is identical to the VAR estimated by Bernanke and Blinder (1992). The semi-structural moving average representation is as follows.

$$\begin{bmatrix} \pi \\ dy \\ i \end{bmatrix} = \begin{bmatrix} & 0 & 0 \\ & & 0 \\ & & \end{bmatrix} \begin{bmatrix} \varepsilon^{\pi} \\ \varepsilon^{dy} \\ \varepsilon^{i} \end{bmatrix} \tag{1.8}$$

The two zeros in the last column of the response matrix follow from the assumption that federal funds rate changes do not impact inflation (π) or output growth (y) within the same month. This is a reasonable assumption given the usual “long and variable” lags argument and it is the identifying restriction imposed by Bernanke and Blinder.[1] The zero in the second column of the first row follows from the assumption that the innovation to output growth does not impact inflation within the same month. This assumption is consistent with a nominal

[1] They alternatively imposed the restriction that policy does not react to output growth and inflation within the same month. Christiano, Eichenbaum and Evans (1994) conclude that the more reasonable restriction is that policy does not impact output growth or inflation contemporaneously.

rigidities story. However, it is less firmly grounded than the first but at the same time it is also less important because we are interested in measuring the response of inflation and output growth to changes in monetary policy. Thus, the exact parsing of the contributions of ε^{π} and ε^{y} will not affect the impulse responses or variance decompositions of inflation and output growth with respect to federal funds innovations. The elements of the matrix that are not labeled with zeros are estimated.[2]

We estimated this VAR over the period January 1988 through November 2003. We chose 1988 as the starting point because, as mentioned above, Bernanke and Mihov found that the federal funds interest rate is a good indicator of monetary policy over this period. The data for the price level is the consumer price index less food and energy, the data for real output is total industrial production. Inflation and output growth were computed by multiplying 1200 times the differenced logs of the price level and real output respectively. The data are displayed in Figures 4-6. Figure 6 shows the clear inverse relationship between the slope of the yield curve and the federal funds interest rate.

The VAR is estimated with 3 lags of each variable. This lag length was chosen after examining several criteria (see explanation below for how we chose the lag length for the four-variable VAR—we followed the same procedure here as well). The impulse responses for the benchmark model are shown in Figures 7-9. The important finding is that the inflation rate responds positively to monetary tightening (bottom panel of Figure 7). The inflation puzzle is alive and well in the sample from 1988 through 2003. Note that there is also a bit of a real output puzzle (bottom panel of Figure 8)—real output growth responds positively to monetary tightening.[3]

We next estimated our four variable VAR consisting of the inflation rate, real output growth, the federal funds rate and the yield curve slope. The yield curve slope (denoted by s) is defined as the 10 year Treasury bond rate minus the 3 month T-bill rate. Our hypothesis is that a monetary tightening raises short-term interest rates and flattens the yield curve slope. A monetary easing lowers short-term interest rates and steepens the yield curve. In order to make our impulse responses directly comparable to the 3-variable benchmark impulse responses we multiplied the yield curve slope by negative 1 so that a rise in the yield curve slope represents a monetary tightening and a fall in the yield curve slope represents a monetary easing.

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[2] Estimation is subject to the usual restriction on the relationship between the variance of the estimated residuals and the variance of the structural shocks. In particular, if A(0) is the matrix of contemporaneous responses to the structural shocks, Σ is the diagonal covariance matrix of those shocks and Ω is the covariance matrix of the estimated residuals from the VAR then $A(0)A(0)'\Sigma=\Omega$ imposes 6 restrictions on the elements of the A(0) matrix in the 3 variable VAR and 10 restrictions on the elements of the A(0) matrix in a 4 variable VAR.

[3] Bernanke and Mihov (1998) also found this real output puzzle which they attribute to inventory accumulation at the beginning of a downturn. They also claim that this puzzle disappears when quarterly data are used.

The semi-structural moving average representation of the 4 variable VAR is as follows:

$$\begin{bmatrix} \pi \\ dy \\ s \\ i \end{bmatrix} = \begin{bmatrix} & 0 & 0 & 0 \\ & & 0 & 0 \\ & & & 0 \\ & & & \end{bmatrix} \begin{bmatrix} \varepsilon^{\pi} \\ \varepsilon^{dy} \\ \varepsilon^{mp} \\ \varepsilon^{reveal} \end{bmatrix} \tag{1.9}$$

The key identifying restriction is that the innovation ε^{reveal} has no contemporaneous impact on the yield curve slope. This is the part of the (reduced form) innovation to the federal funds rate that reveals the Fed's superior information about the future path of inflation. The remaining movements in the yield curve slope and the federal funds rate are due to the remaining three shocks: contemporaneous (as opposed to forecasted) inflation (ε^{π}), contemporaneous output growth (ε^{dy}) and monetary policy (ε^{mp}). The monetary policy shock is identified as above and it follows Bernanke and Blinder's identification restriction that monetary policy has no contemporaneous impact on inflation or output growth. The remaining zero elements of the matrix determines the split between the inflation and output growth shock, which for the purposes of this paper are not important. The remaining elements of the matrix that are not marked are estimated subject to the usual restrictions on the relationship between the covariance matrix of the estimated residuals and the covariance matrix of the structural shocks.

The bottom equation of our three-variable VAR is essentially a Taylor-type monetary policy rule measuring the Fed's reaction to inflation and growth shocks. But this is a backward-looking policy rule in the sense that the growth and inflation shocks represent contemporaneous movements in growth and inflation not captured by their own pasts. As demonstrated by Orphanides (2001) the Fed most likely reacts to its own 4-quarter-ahead forecast of the economy. So there are (at least) two differences between what the three variable VAR represents in terms of monetary policy and Orphanides' Taylor-rule. First, it is backwards looking and second, it does not capture the type of information that Romer and Romer (2000) suggest make the Fed's forecasts superior—the anecdotal information and the detailed information about sectors and regions that is provided by the large staff of economists working at the Board and the regional Fed banks. It is impossible to determine which of these is most important. But we suggest that one way to look at the results of the three variable VAR is as follows. If we assume that lagged growth and inflation are sufficient statistics for the private sector's forecast of growth and inflation, then the three variable VAR captures the private sector's forecast of growth and inflation. A positive monetary policy shock in this three variable VAR therefore represents an increase in the federal funds rate given the private sector's forecast. What we are suggesting is that this innovation is a combination of the Fed's superior information and a real Fed tightening.

Contrast the above-interpretation of the Taylor-rule with the third and fourth equations in our four-variable VAR. The third equation, the negative of the yield curve slope, is now the monetary-policy reaction function. Innovations to this equation are now purged of changes in the federal funds rate that the public believes reveal new information about the Fed's forecast of future output growth and inflation. Moreover, as long as we continue to assume that past growth and inflation are sufficient statistics for the private sector's forecast, then the third equation represents a Taylor-type rule where the Fed's reactions to inflation and output growth are no longer contaminated by its revelation of information (which is captured by changes in the federal funds rate that cause no contemporaneous change in the yield curve slope.)

Model Evaluation and Design Criteria

Lag Length Selection

The selection criteria for the appropriate lag length of the unrestricted VAR models employ χ^2 test(s). The maximum possible lag length considered was twelve, the number of months in a year. The Bayesian Schwartz Criterion (BSC), the Akaike Information Criterion (AIC), and the Hannan-Quinn Criterion are used as alternative criterion. They rely on information similar to the Chi-Squared tests and are derived as follows:

$$\begin{aligned} AIC &= \log\left(Det\,\hat{\Sigma} \right) + 2*c*T^{-1} \\ BSC &= \log\left(Det\,\hat{\Sigma} \right) + 2*c*\log(T)T^{-1} \\ HC &= \log\left(Det\,\hat{\Sigma} \right) + 2*c*\log(\log(T))*T^{-1} \end{aligned} \tag{1.10}$$

Intuitively, the log determinant of the estimated residual covariance matrix will decline as the number of regressors increases, just as in a single equation ordinary least squares regression. It is similar to the residual sum of squares or estimated variance. The second term on the right hand side acts as a penalty for including additional regressors; it increases the statistic. We calculate these statistics for each lag length and choose the lag length based on the model(s) with the minimum value for the statistics. The three tests do not always agree on the same number of lags. The AIC is biased towards selecting more lags than is actually needed; this is not necessarily bad. We concluded that the BSC and HC were minimized with three lags and the AIC was minimized with four lags for both the three and four variable VAR models.

Model Stability Tests

There were several incidents which could have influenced the stability of the relationship between monetary policy and the economy over our sample period. These included two recessions, financial crisis in the bond and credit markets in the late 1980s, 1997, and 1998. In addition, there was a major Fed Policy change in February 1994 regarding the announcement of FOMC decisions. Any or all of these events could have contributed to a “structural” break in the data generating process for inflation, output growth, and the yield curve.

The textbook approach to model constancy assumes that the modeler knows the date of a possible structural break in the sample. He/she fits the model over the full sample and for the two “halves” of the sample. The full sample implicitly imposes the same model structure throughout and can be considered a restricted model. This is evaluated against the unrestricted model comprised of the two “halves” using an F-test. We take an agnostic view on the possibility and timing of structural breaks over the 1988-2003 sample.

Model constancy of the VAR system is evaluated using recursive estimation techniques. Suppose the original model has T observations. The technique begins by estimating the model over first s<T observations in the sample and then fit the model using s+1, s+2, ..., up to T observations. At this point there are a number of tests for evaluating model (and parameter) constancy. They are often best presented in graphical form, because of the large number of statistics which are calculated.

A familiar statistical presentation is the 1-step ahead residuals plus the standard error bound used to search for outliers. The 1-step residuals are given by $\hat{e}_t = y_t - x_{t'}\hat{\beta}_t$ and plotted with the current estimate of +/-2 $\hat{\sigma}_t$ on either side of zero. When $\hat{e}_t$ is outside the band it can be interpreted as an outlier. Standardized innovations are another way to illustrate the presence of outliers.

We report two types of recursive Chow tests. The first is the 1-step Chow test. This looks at the sequence of one period ahead predictions from the recursive estimation for period s to T. The tests are F(1,t-k-1) under the null hypothesis of parameter constancy. The statistic is calculated as:

$$\left(\frac{(RSS_t \; - \; RSS_{t-1})\,(t-k-1)}{RSS_{t-1}}\right) \; : \quad F\,(1,t-k-1) \quad where \quad t \; = \; s \; , \; \; s+1, \ldots, T \tag{1.11}$$

The test assumes that the dependent variables, y_t, are approximately normally distributed.

The *N-down test or Break-Point Chow test* plots the test statistic over the sample scaled by either the 5% or 1% critical value and can be interpreted as a forecast stability test. The model is estimated for the first s observations. A forecast is constructed from period s+1 through T and the F-test is calculated. The null hypothesis is that the estimated model and forecast will explain or predict the full sample as the same the full sample. The number of periods in the forecasts goes down from T-s+1 to 1 as the model is estimated and forecasts are performed recursively. Recursive estimation permits construction of Chow tests over the full sample and lets the data do the talking. The *Break-Point Chow test* is calculated as:

$$\left(\frac{(RSS_T \;-\; RSS_{t-1})\,(t-k-1)}{RSS_{t-1}\;/\;(T-s-1)} \right) \;:\; F\,(T-s+1, t-k-1) \quad where \quad t \;=\; s\;,\;\; s+1, \ldots, T \tag{1.12}$$

The results of the 1-step ahead Chow tests and the Break-point Chow test are presented graphically in Figures 10 and 11 respectively. At each observation the normalized test statistic calculated as the ratio of the statistic to the appropriate critical value at 1%. The sequence of tests is plotted. When the normalized value exceeds unity, this indicates a rejection of the null hypothesis of no structural break.

The 1-step ahead Chow test results indicate a single spike in August 1998 for output growth, April 1999 for inflation, and early 2001 for the Federal Funds rate. The output shock was a large rebound from July estimate of more than 20% on an annual basis. The inflation shock begins a period of increased volatility in the inflation process. Monthly annualized fluctuations appear to increase from about 4% during the 1991 to 1999 period to nearly 8% for the remainder of the sample. In 2001 the Fed began a lengthy series of rate cuts to moderate the recession. The 1-step ahead Chow tests for the whole VAR or system in the final (fifth) graph, there is only a single observation over 186 observations where the null hypothesis is rejected. This occurs at the same time as the one in the Federal Funds equation.

The Break-point Chow tests presented in Figure 11 do suggest some instability in the system. However the output and Federal Funds rate equations appear to be stable over the full sample. There are two periods in the inflation equation where the null hypothesis is rejected: the second halves of 1998 and 1999. These periods coincide with rejections in the yield curve equation. This equation appears to be fairly unstable throughout the sample and includes another period of rejection in 1993. During the late 1990s credit markets in the U.S. were flooded with foreign funds seeking safety, particularly in shorter-term Treasuries following financial crises in Russia, Southeast Asia, and Latin America. Risk spreads even on investment grade bonds increased along with the yield curve. One possible source of instability in the inflation process could arise from changes to the way that the CPI was calculated. The BLS phased in several changes starting in 1996. Because of these changes, the Fed has started tracking the PCE deflator. The system as a whole appears stable over the full sample (graph 5), but is close to rejection during the 2nd half of 1998 through 2000.

Granger Causality Tests

Table 2 shows the Granger Causality tests for this 4-variable model. Each of the 4 variables appears to have explanatory power for one or more of the other variables in the system. Lagged values of the yield curve slope have marginal power in explaining inflation and no power in explaining output growth. Lagged values of the fed funds rate are significant in explaining inflation but only marginally significant in explaining output growth. Lagged values of the fed funds rate also explain movements in the yield curve slope and lags of the yield curve slope (marginally) as well as lags of output growth explain movements in the fed funds rate.

6. VAR Results: Impulse Responses and Variance Decompositions

The impulse responses for this model are shown in Figures 12 through 15. The responses we are mainly interested in looking at are the responses to ε^{mp} and ε^{reveal}. The response to ε^{mp} is measured as the response to YCI (the yield curve multiplied times -1) which is shown in the southwest panel of each of the figures. These responses are the responses to monetary policy once we have removed the part of monetary policy that is signaling forecasted inflation by the Fed. The response to ε^{reveal} is measured as the response to FEDFUND which is shown in the southeast panel of each of the figures. These responses are the responses of each of the 4 variables to the Fed's revelation of future inflation. Each response is surrounded by a two standard error band (computed analytically, using EVIEWS).

The response of inflation to YCI shown in Figure 12 is negative and at horizons past 6 months the response is significantly different from zero suggesting that monetary policy, measured by ε^{mp} does lead to a decline in inflation. The response of inflation to FEDFUND shown in figure 12 shows the inflation puzzle. This response is almost identical to the response of inflation to the Fed funds rate in figure 7.

Figure 13 shows the output growth (DIP) responses. The response of output growth to ε^{mp} is insignificant throughout and the response of output growth to ε^{reveal} still shows an "output puzzle."

Tables 3 through 6 show the forecast error variance decompositions for this 4-variable system. The orthogonalized innovations to the yield curve slope (YCI) do not explain much of the forecast error variance for either inflation or output growth (Tables 2 and 3). Monetary policy (measured this way) does not seem to matter very much. The orthogonalized innovation to the fed funds rate does explain a small but significant fraction of the forecast error of inflation (Table 3). This is consistent with the theory that these innovations reveal the Fed's superior information about future inflation. Orthogonalized innovations to output growth and the fed funds rate explain about a quarter of the error variance of the yield curve slope at the one-year horizon (Table 5). Finally, orthogonalized innovations to output growth explain about a third of the error variance of the federal funds rate at the one-year horizon (Table 6).

7. Conclusion

In this paper we presented estimates of the responses of output growth and inflation to two orthogonalized shocks: monetary policy and the Fed's revelation of future inflation. The Fed's revelation of future inflation is measured as the innovation to the federal funds rate that has no contemporaneous impact on the yield curve slope. Monetary policy is the remaining part of that innovation.

We found that monetary policy measured this way has little impact on output growth and inflation. Although the impact of monetary policy on inflation is slight, it has the correct sign. Thus, there is no price puzzle with this measure of monetary policy.

References

Anderson, Leonall C. and Jerry L. Jordan, "Monetary and Fiscal Actions: A Test of Their Relative Importance in Economic Stabilization, *Review*, Federal Reserve Bank of St. Louis, November 1968.

Barth, Marvin J. III and Valerie A. Ramey, "The Cost Channel of Monetary Transmission," *NBER Macroeconomics Annual*, 2002.

Bernanke, Ben S. and A. Blinder, "Credit, Money and Aggregate Demand," *American Economic Review*, vol. 82, no. 4, 1992, pp. 901-921.

Bernanke, Ben S. and Ilian Mihov, "Measuring Monetary Policy," *Quarterly Journal of Economics*, vol 113, no. 3, August 1998, pp. 869-902.

Boschen, John and L. Mills, "The Effects of Countercyclical Monetary Policy on Money and Interest Rates: An Evaluation of Evidence from FOMC Documents," Federal Reserve Bank of Philadelphia Working Paper: 91-20, October 1991.

Cook, Thomas and T. Hahn, “The Effect of Changes in the Federal Funds Rate Target on Market Interest Rates in the 1970s,“ *Journal of Monetary Economics*, November 1989, vol. 24, no. 3, pp. 331-51.

Christiano, Lawrence J., M. Eichenbaum and C. Evans, “The Effects of Monetary Policy Shocks: Evidence from the Flow of Funds, *The Review of Economics and Statistics*, vol. 78, no. 1, February 1996, pp. 16-34.

Eichenbaum, Martin, “Comments on Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy,” *European Economic Review*, vol. 36, June 1992, pp. 1001-1011.

Leeper, Eric, C. Sims and T. Zha, “What Does Monetary Policy Do?” *Brookings Papers on Economic Activity*,” 1996:2.

Orphanides, Athanasios, “Monetary Policy Rules Based on Real-Time Data,” *American Economic Review*, vol. 91, no. 4, September 2001, pp. 961-84.

Romer, C. and D. Romer “Does Monetary Policy Matter? A New Test in the Spirit of Friedman and Schwartz.” *NBER Macroeconomics Annual*, 1989:4, pp. 121-170.

____________________ “A New Measure of Monetary Shocks: Derivation and Implications,” unpublished working paper, University of California, Berkeley, June 2003.

Sims, C. “Money, Income and Causality,” *American Economic Review*, vol. 62, no. 4, September 1972: pp. 540-52.

______. “Interpreting Macroeconomic Time Series Facts: The Effects of Monetary Policy.” *European Economic Review*, vol. 36, no. 5, 1992, pp. 975-1000.

_______ and T. Zha, “Does Monetary Policy Cause Recessions?” unpublished manuscript, Yale University, 1994.

Strongin, Steve, “The Identification of Monetary Policy Disturbances: Explaining the Liquidity Puzzle, *Journal of Monetary Economics*, vol. 35, June 1995, pp. 463-498.

__________________________________, “Federal Reserve Information and the Behavior of Interest Rates,” *American Economic Review*, vol. 90, no. 3, June 2000, pp. 429-457.

Figures and Tables

Figure 1

Relationship Between Changes in Long-Term Rates and Changes in the Yield Curve Slope

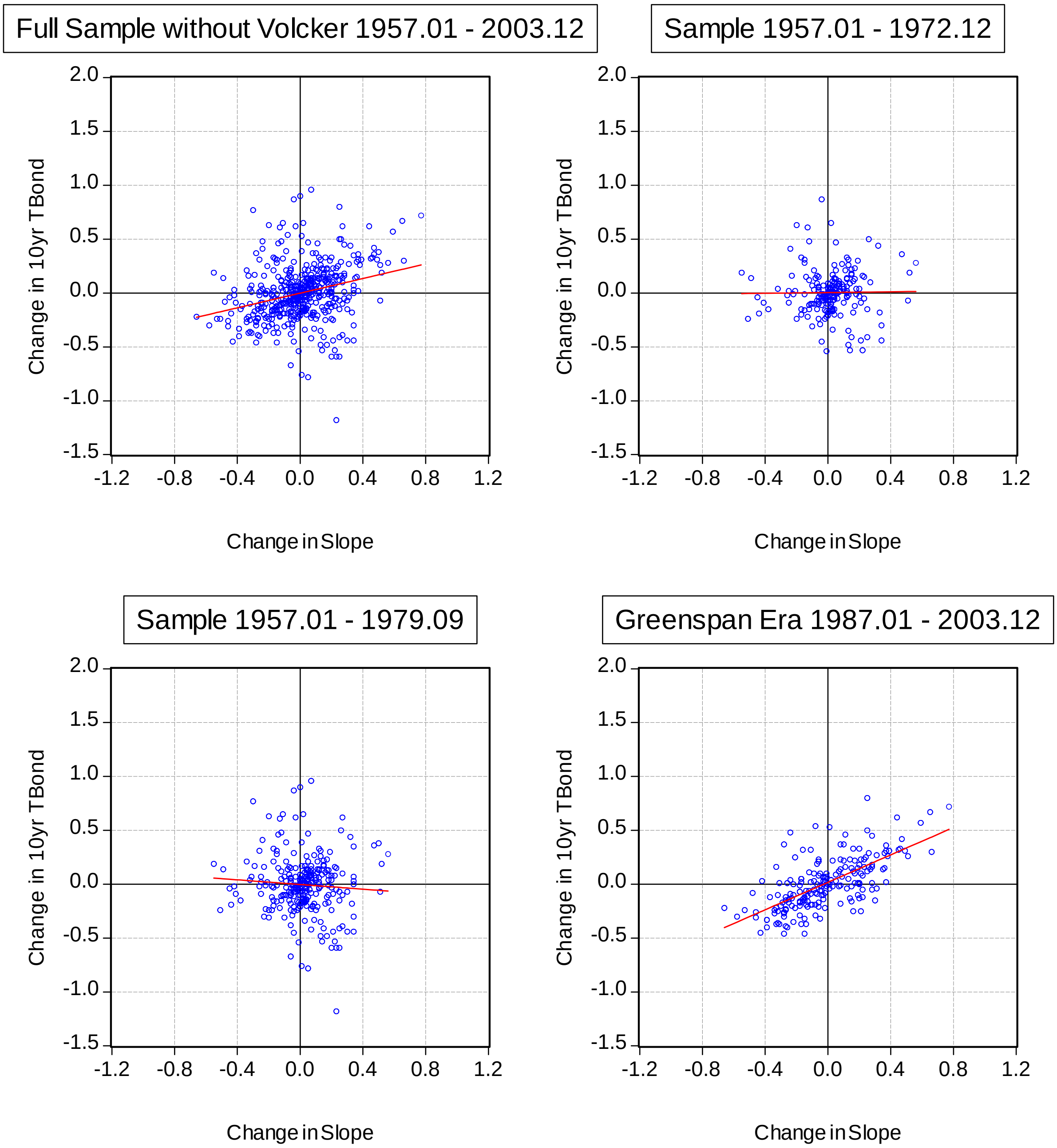


Figure 2

Relationship Between Changes in Short-Term Rates and Changes in the Yield Curve Slope

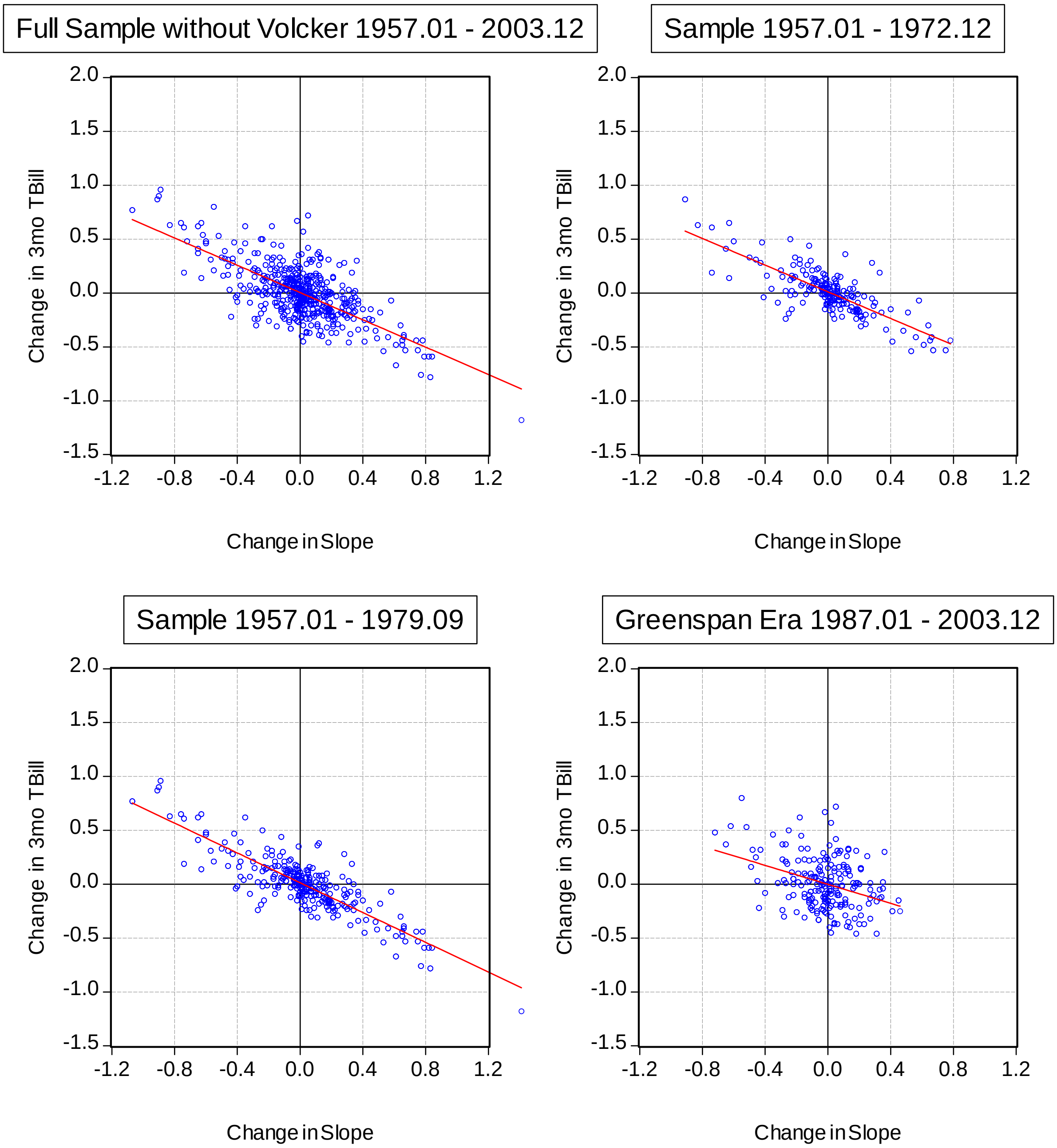


Figure 3

Relationship Between Changes in Fed Funds Rate and Changes in the Yield Curve Slope

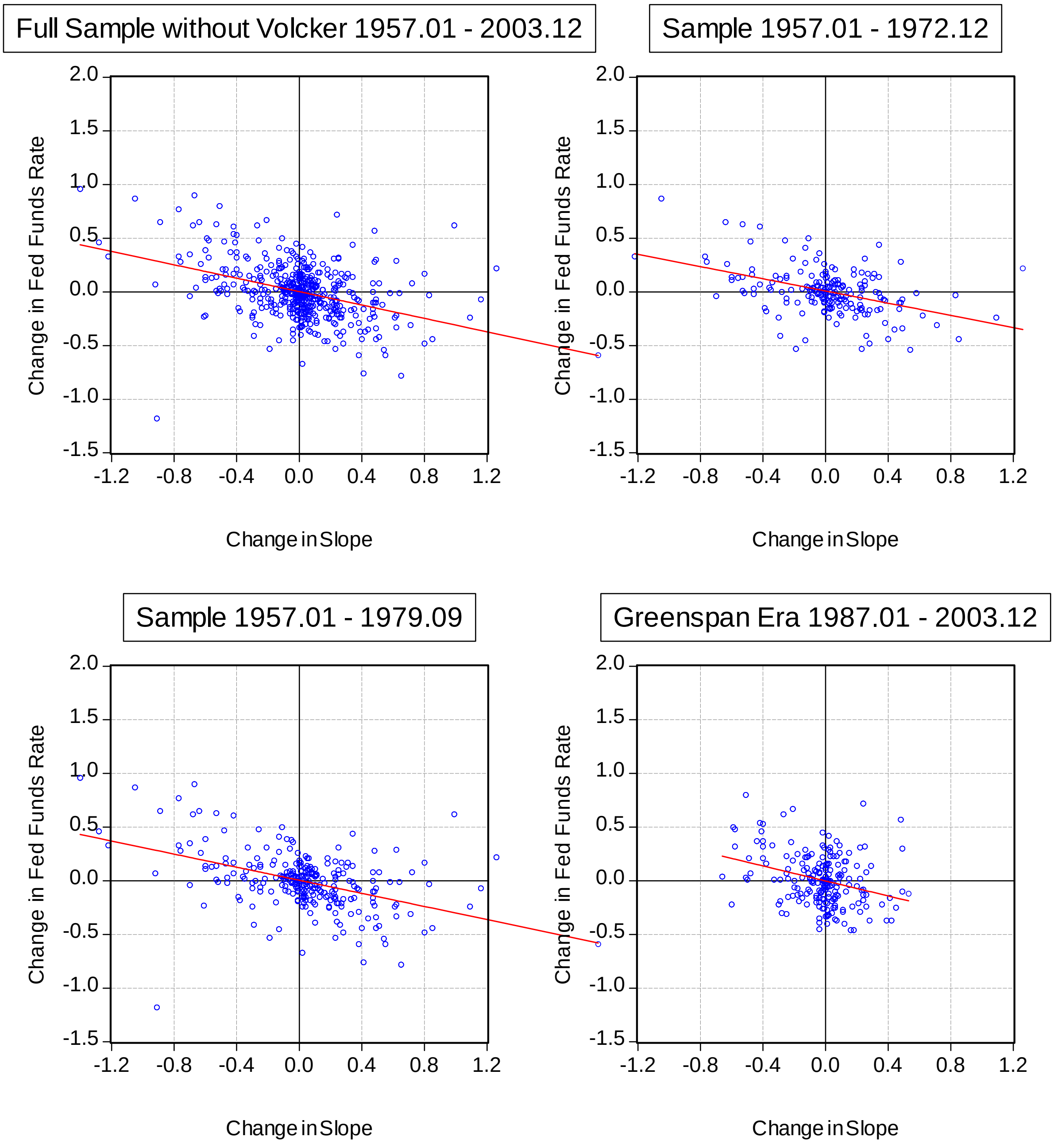


Figure 4

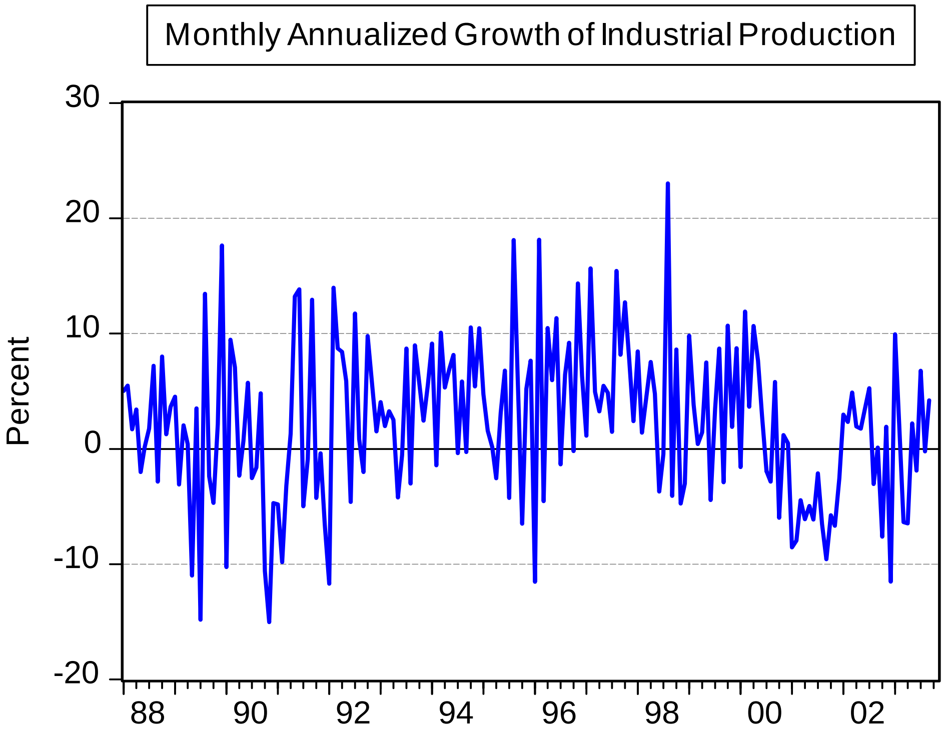


Figure 5

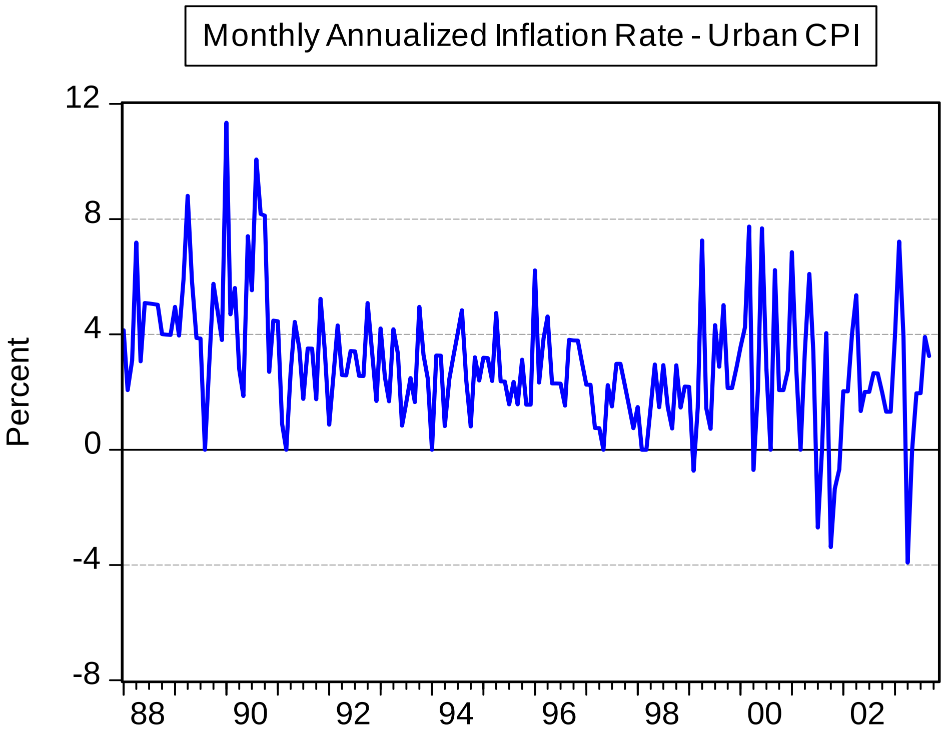


Figure 6

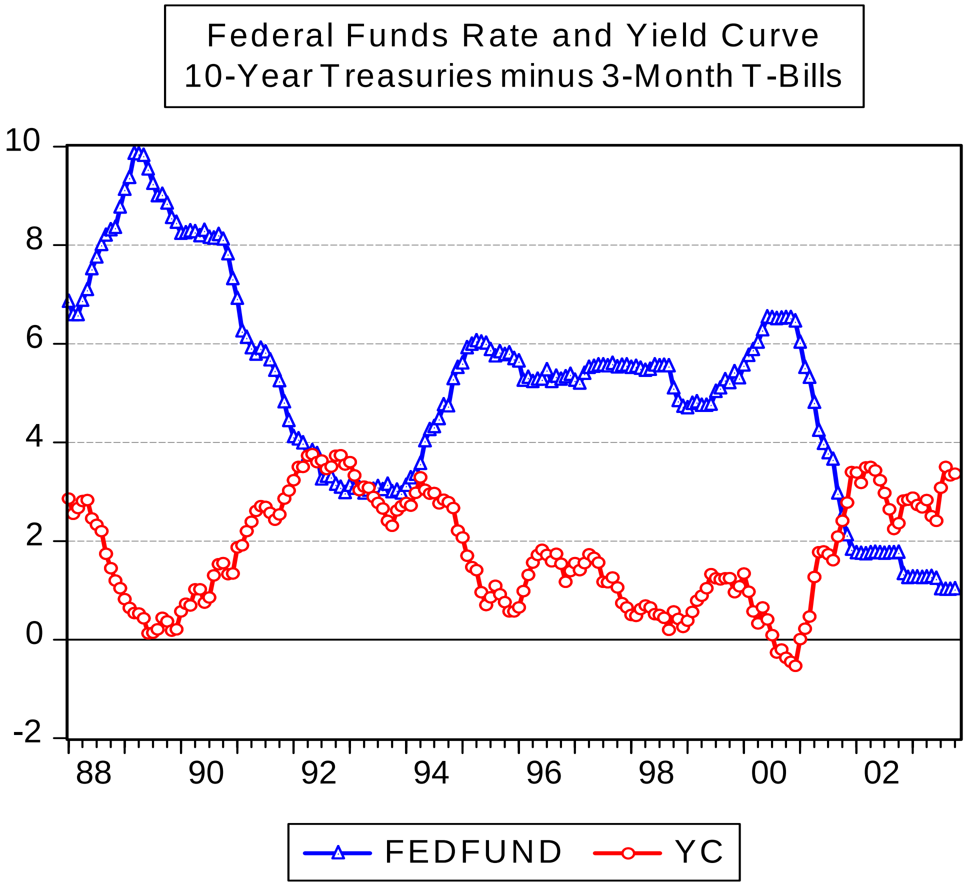

Federal Funds Rate and Yield Curve
10-Year Treasuries minus 3-Month T-Bills
10
8
6
4
2
0
-2
88
90
92
94
96
98
00
02
FEDFUND
YC

Figure 7: Impulse Responses For Inflation (INF)

Benchmark Model

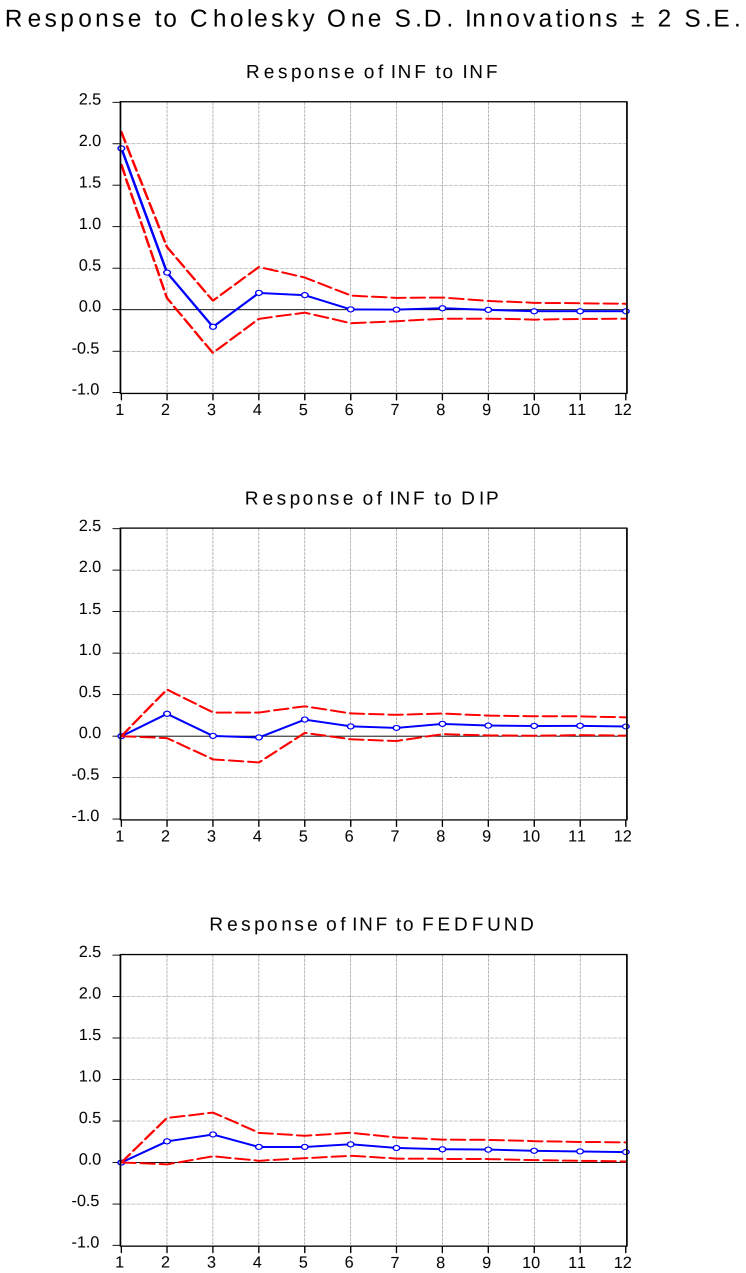


Figure 8: Impulse Responses for Output Growth (DIP)

Benchmark Model

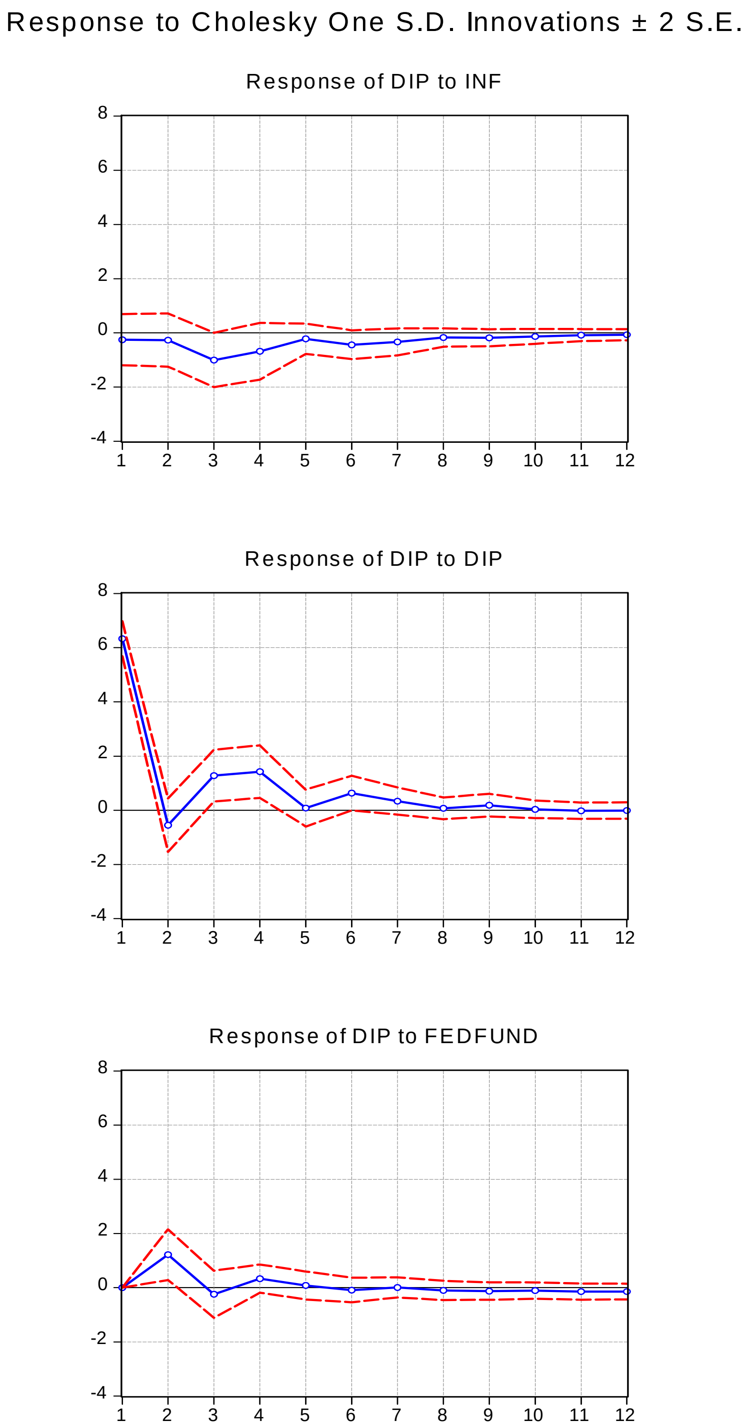


Figure 9: Impulse Responses for FEDFUNDS

Benchmark Model

Response to Cholesky One S.D. Innovations ± 2 S.E.

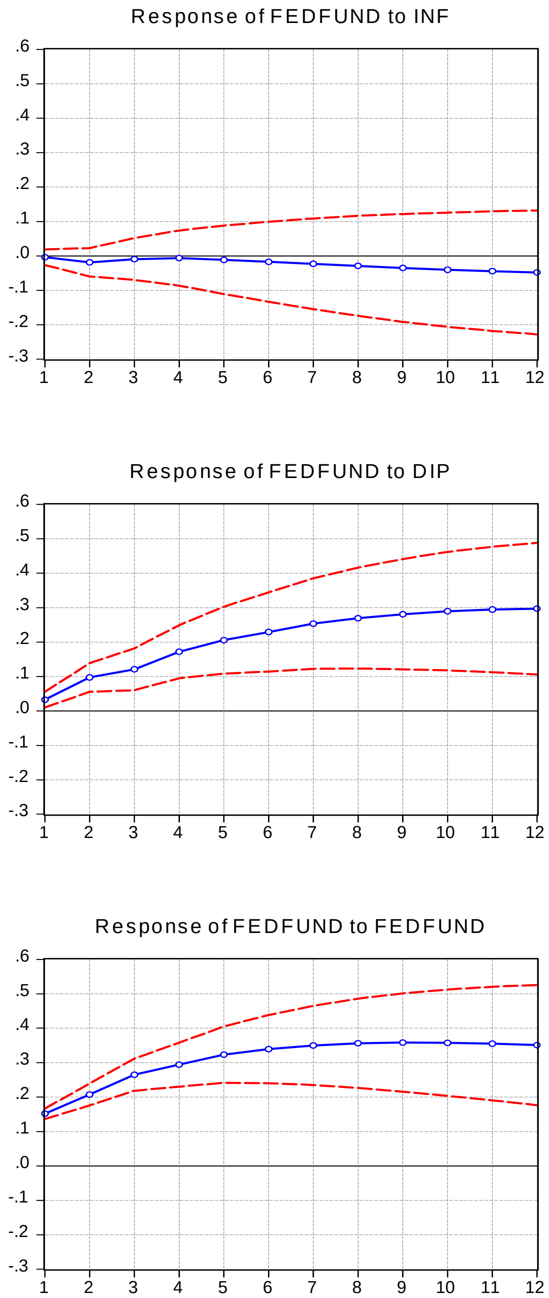


Figure 10

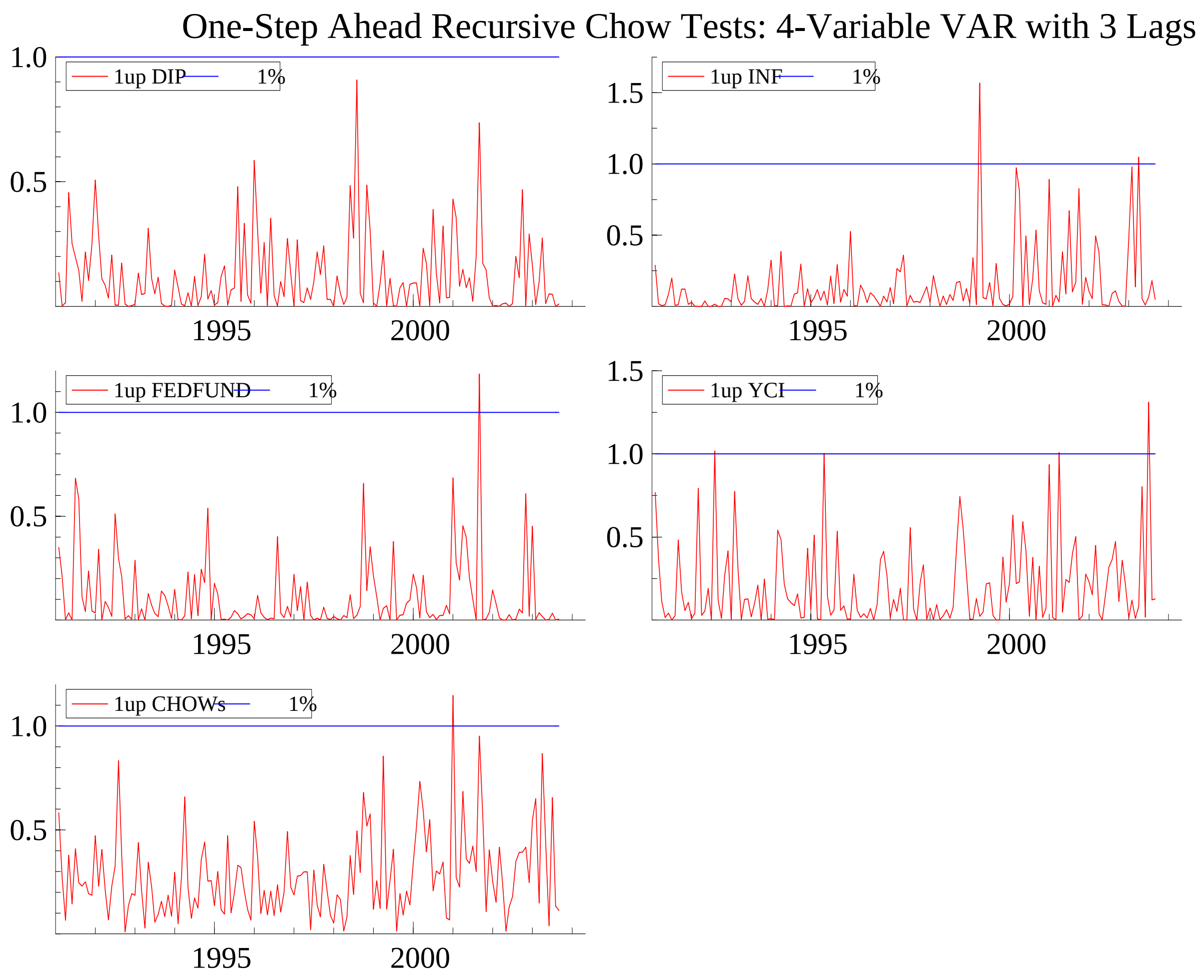

One-Step Ahead Recursive Chow Tests: 4-Variable VAR with 3 Lags
1up DIP
1%
1up INF
1%
1up FEDFUND
1%
1up YCI
1%
1up CHOWs
1%
1.0
0.5
1.5
1995
2000

Figure 11

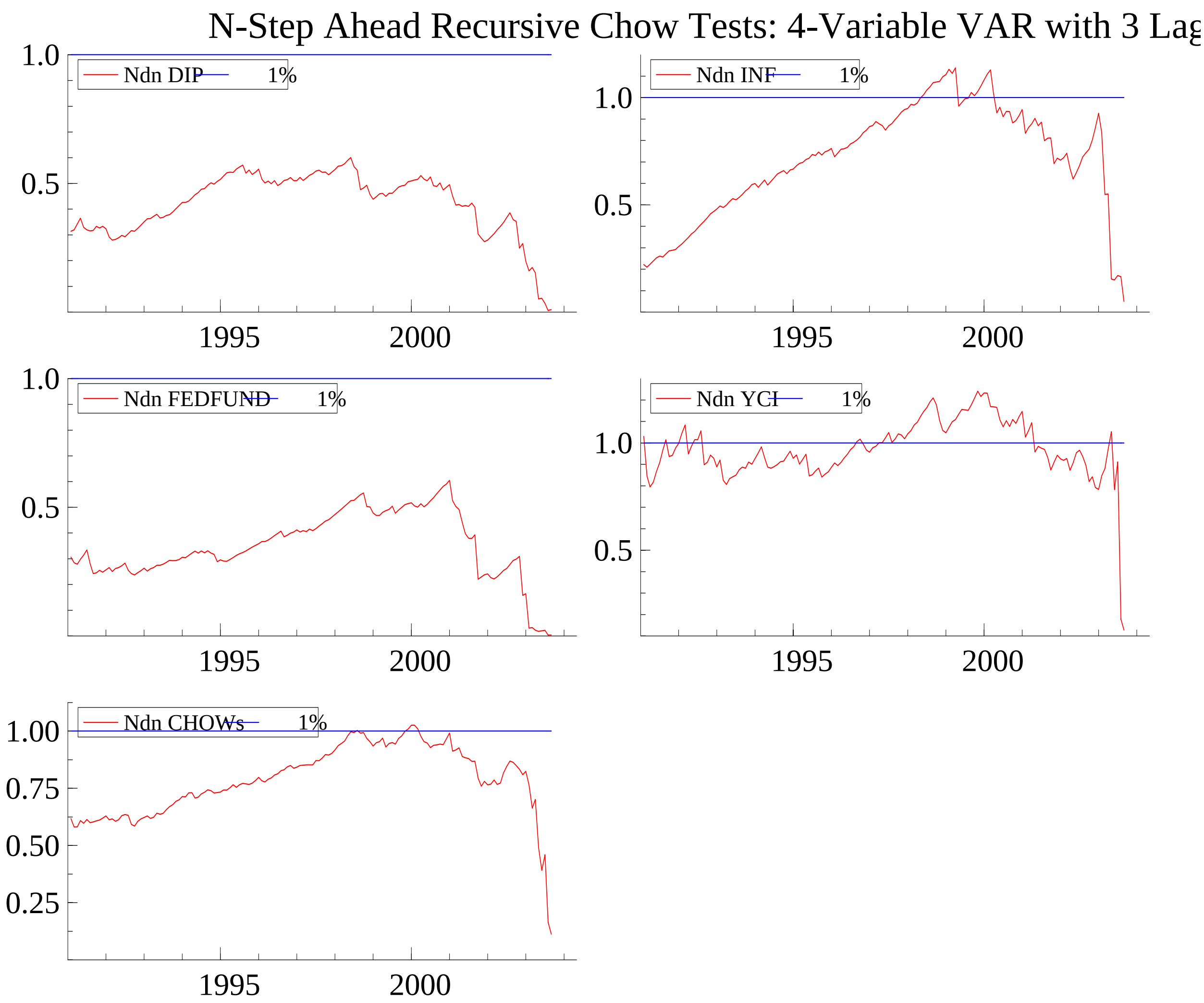

N-Step Ahead Recursive Chow Tests: 4-Variable VAR with 3 Lag
Ndn DIP
1%
Ndn INF
1%
Ndn FEDFUND
1%
Ndn YCI
1%
Ndn CHOWs
1%
1.0
0.5
1.00
0.75
0.50
0.25
1995
2000

Figure 12: Impulse Responses For Inflation (INF)

4 Variable VAR

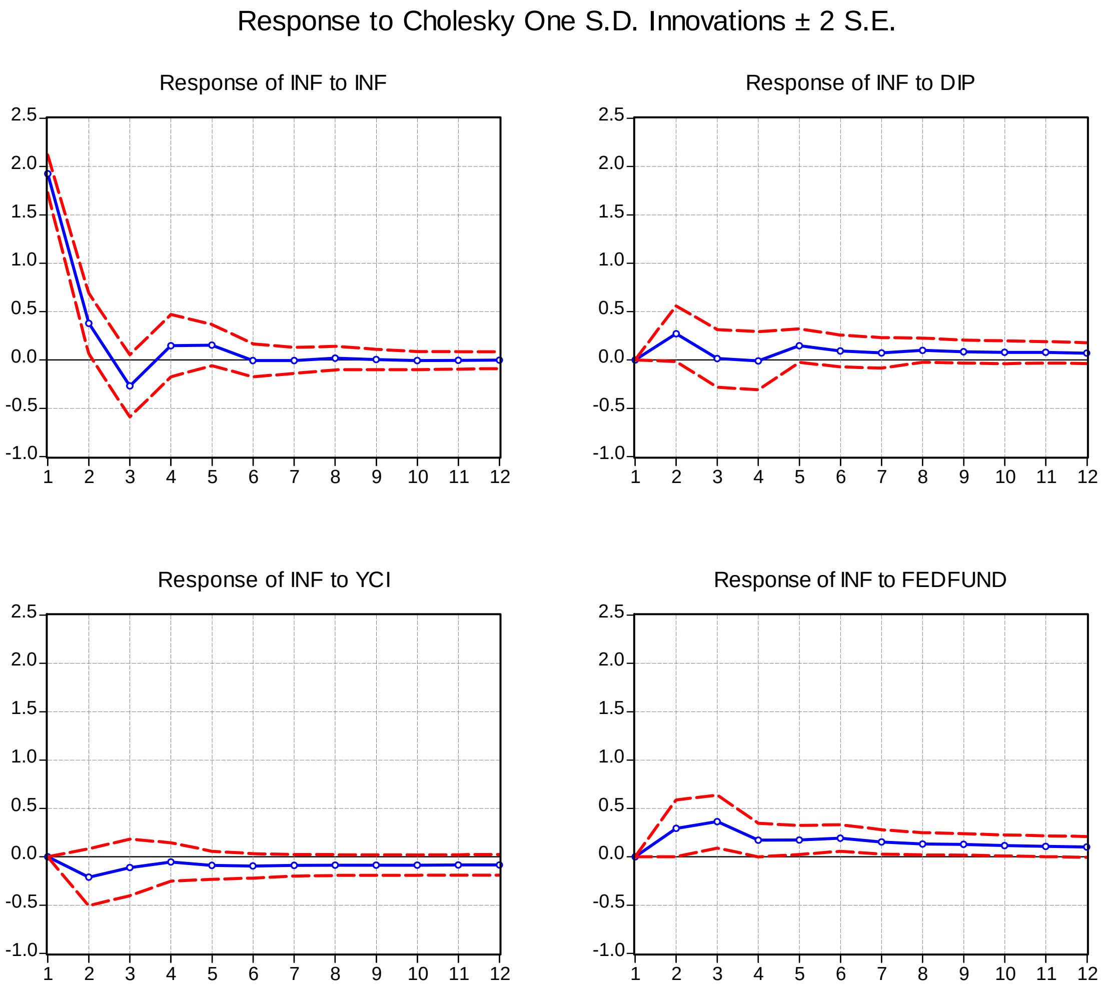


Figure 13: Impulse Responses For Output Growth (DIP)

4 Variable VAR

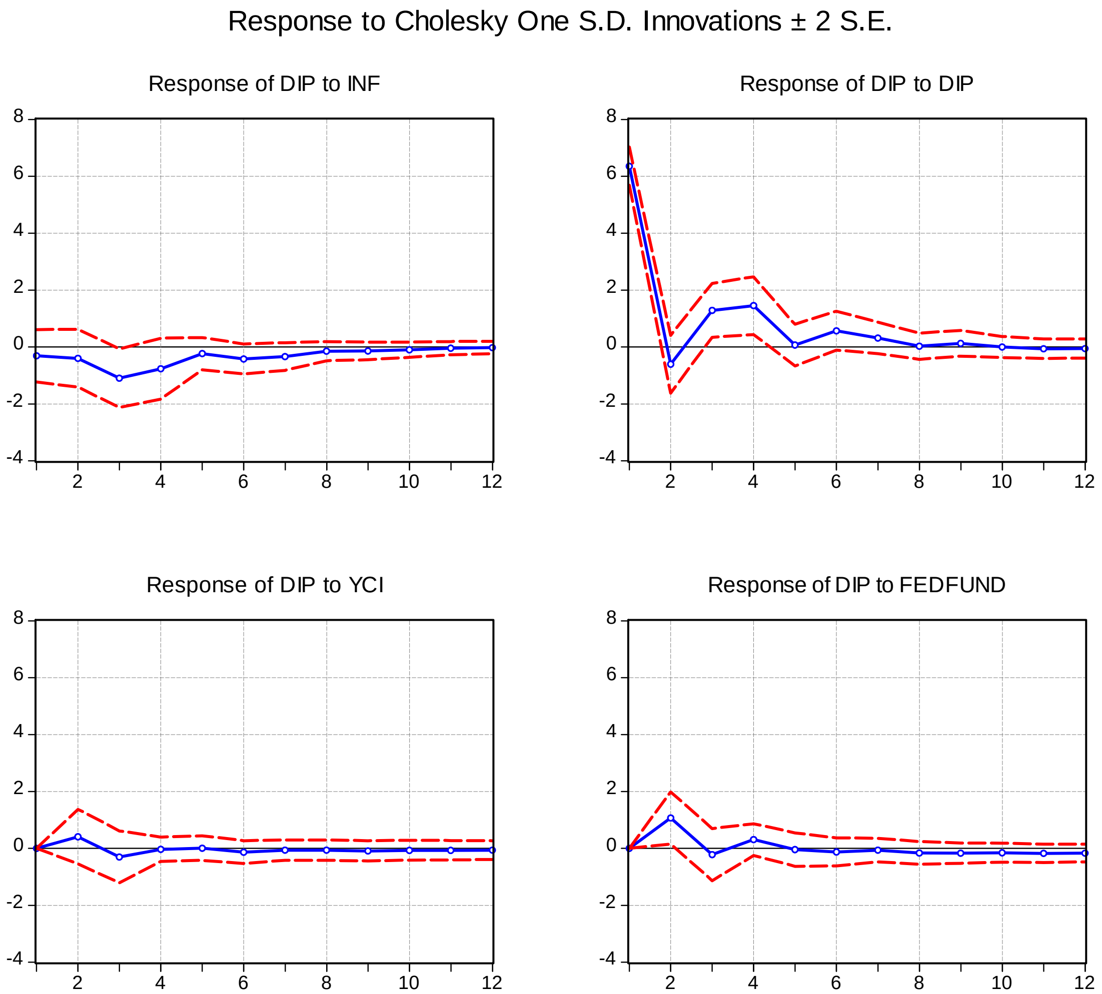


Figure 14: Impulse Responses For Inverse of Yield Curve Slope (YCI)

4 Variable VAR

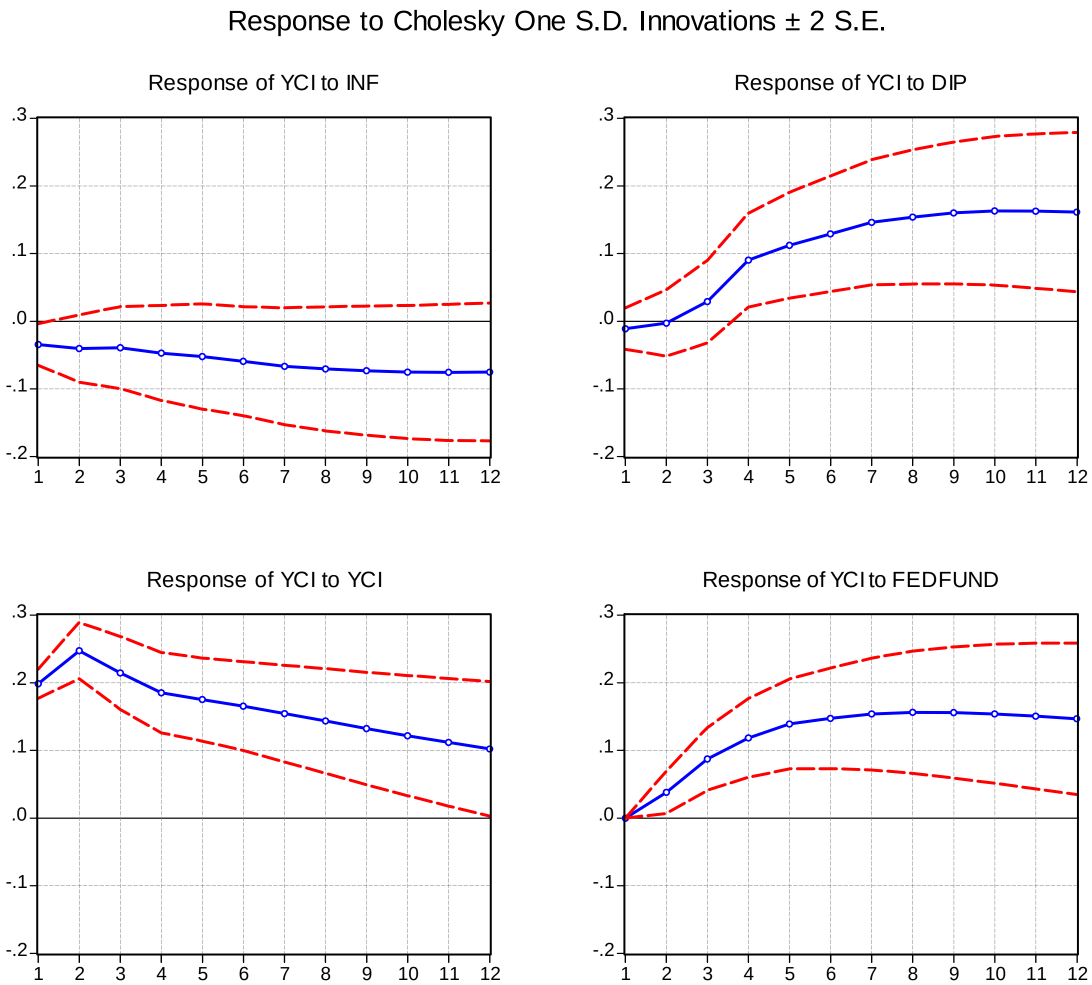
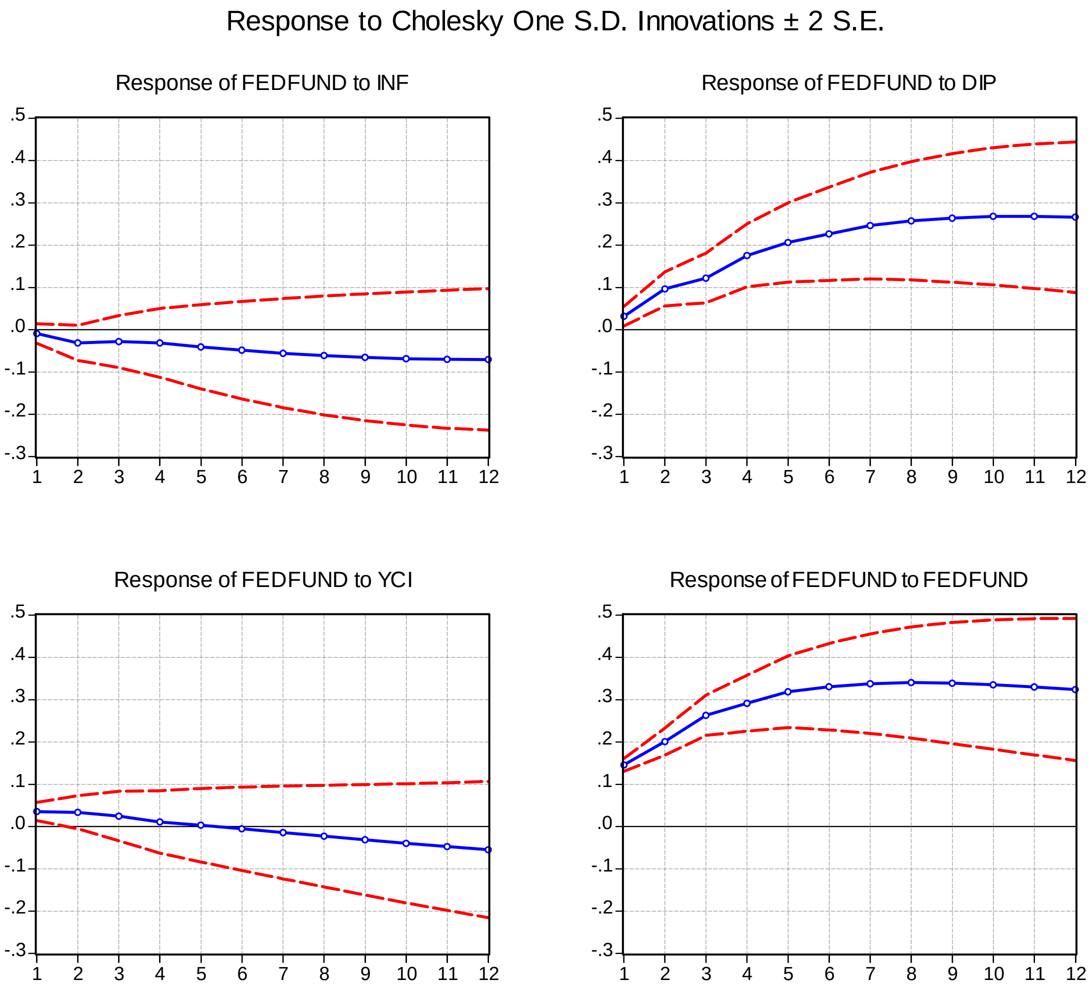


Figure 15: Impulse Responses For FEDFUNDS

4 Variable VAR



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Possible Impacts of an Increase in the Federal Funds Rate</th></tr>
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<tr><td>< 0</td><td>= 0</td><td>0 ></td></tr>
<tr><td rowspan="3">$\Delta\pi_S^e - \Delta\pi_L^e$</td><td>< 0</td><td>tilt</td><td></td><td></td></tr>
<tr><td>= 0</td><td></td><td>Subcase 1: tilt
Subcase 2: shift</td><td></td></tr>
<tr><td>0 ></td><td></td><td></td><td>tilt</td></tr>
</table>

Table 2

Four Variable VAR System: Granger Causality Tests

Sample 1988:01 – 2003:11

Restrictions/ Dep. Var.	Inflation	Output Growth	Yield Curve	Fed Funds	Joint Test
Inflation	-	4.30 (0.23)	6.66 (0.08)	22.06 (0.00)	29.14 (0.00)
Output Growth	8.28 (0.04)	-	1.43 (0.70)	6.42 (0.09)	15.73 (0.07)
Yield Curve	0.17 (0.98)	5.71 (0.13)	-	15.98 (0.00)	40.98 (0.00)
Fed Funds	4.71 (0.19)	24.59 (0.00)	6.81 (0.08)	-	37.89 (0.00)

The dependent variable is presented in the first column and the Chi-squared results for the zero restrictions are given along the rows. The VAR includes three lags and the joint test includes nine zero restrictions. P-values are provided in the parentheses.

Table 3: Variance Decompositions for Inflation

Period	S.E.	Inflation	Output Growth	Yield Curve	Fed Funds
1	1.93	100.00	0.00	0.00	0.00
		0.00	0.00	0.00	0.00
2	2.01	94.98	1.80	1.10	2.12
		(3.17)	(1.99)	(1.59)	(1.98)
3	2.07	91.85	1.72	1.33	5.10
		(3.86)	(2.01)	(1.81)	(2.85)
4	2.08	91.20	1.70	1.38	5.72
		(4.05)	(2.09)	(1.82)	(3.13)
5	2.10	90.02	2.15	1.53	6.29
		(4.35)	(2.37)	(1.81)	(3.32)
6	2.11	88.91	2.32	1.71	7.05
		(4.64)	(2.43)	(1.90)	(3.60)
7	2.12	88.19	2.42	1.87	7.52
		(4.84)	(2.48)	(1.97)	(3.79)
8	2.13	87.50	2.63	2.02	7.85
		(5.05)	(2.59)	(2.04)	(3.93)
9	2.14	86.91	2.77	2.17	8.16
		(5.21)	(2.65)	(2.12)	(4.04)
10	2.14	86.39	2.89	2.32	8.40
		(5.37)	(2.72)	(2.22)	(4.14)
11	2.15	85.92	3.00	2.46	8.61
		(5.51)	(2.79)	(2.32)	(4.22)
12	2.15	85.51	3.10	2.60	8.79
		(5.65)	(2.85)	(2.43)	(4.29)

Analytic standard errors are in parentheses below the estimates.

Table 4: Variance Decompositions for Output Growth

Period	S.E.	Inflation	Output Growth	Yield Curve	Fed Funds
1	6.36	0.23	99.77	0.00	0.00
		(1.01)	(1.01)	0.00	0.00
2	6.51	0.60	96.31	0.40	2.69
		(1.50)	(2.91)	(1.08)	(2.34)
3	6.73	3.22	93.60	0.57	2.62
		(2.69)	(3.73)	(1.34)	(2.34)
4	6.94	4.24	92.56	0.54	2.66
		(3.01)	(3.91)	(1.29)	(2.43)
5	6.94	4.34	92.46	0.54	2.66
		(3.12)	(4.03)	(1.31)	(2.46)
6	6.98	4.66	92.10	0.57	2.67
		(3.35)	(4.21)	(1.35)	(2.44)
7	6.99	4.87	91.90	0.57	2.66
		(3.50)	(4.32)	(1.37)	(2.44)
8	7.00	4.91	91.80	0.58	2.71
		(3.54)	(4.37)	(1.40)	(2.44)
9	7.00	4.94	91.70	0.59	2.77
		(3.58)	(4.42)	(1.43)	(2.45)
10	7.01	4.95	91.63	0.60	2.81
		(3.60)	(4.45)	(1.47)	(2.45)
11	7.01	4.95	91.57	0.61	2.87
		(3.60)	(4.48)	(1.50)	(2.47)
12	7.01	4.95	91.51	0.62	2.92
		(3.61)	(4.51)	(1.54)	(2.49)

Analytic standard errors are in parentheses below the estimates.

Table 5: Variance Decompositions for the Yield Curve Slope

Period	S.E.	Inflation	Output Growth	Yield Curve	Fed Fund
1	0.20	2.92	0.29	96.79	0.00
		(2.43)	(1.10)	(2.63)	0.00
2	0.32	2.69	0.12	95.83	1.37
		(2.61)	(1.07)	(3.03)	(1.12)
3	0.40	2.71	0.60	91.04	5.65
		(2.98)	(1.44)	(4.38)	(2.95)
4	0.47	2.99	4.15	82.34	10.52
		(3.45)	(3.28)	(6.25)	(4.71)
5	0.53	3.26	7.62	74.22	14.90
		(3.88)	(4.96)	(7.65)	(6.02)
6	0.60	3.61	10.84	67.44	18.11
		(4.26)	(6.28)	(8.62)	(7.01)
7	0.65	4.03	13.99	61.45	20.53
		(4.65)	(7.38)	(9.32)	(7.79)
8	0.71	4.42	16.67	56.52	22.39
		(5.02)	(8.28)	(9.83)	(8.46)
9	0.76	4.79	19.02	52.40	23.79
		(5.35)	(9.01)	(10.20)	(9.02)
10	0.80	5.14	21.06	48.94	24.86
		(5.65)	(9.62)	(10.47)	(9.50)
11	0.84	5.46	22.78	46.07	25.69
		(5.92)	(10.11)	(10.67)	(9.91)
12	0.88	5.74	24.27	43.64	26.36
		(6.16)	(10.52)	(10.83)	(10.27)

Analytic standard errors are in parentheses below the estimates.

Table 6: Variance Decompositions for the Federal Funds Rate

Period	S.E.	Inflation	Output Growth	Yield Curve	Fed Fund
1	0.15	0.33	4.31	5.39	89.96
		(1.10)	(2.97)	(3.15)	(4.38)
2	0.27	1.39	13.71	3.18	81.72
		(1.99)	(5.25)	(2.55)	(6.03)
3	0.40	1.14	15.71	1.87	81.28
		(2.09)	(6.18)	(2.16)	(6.80)
4	0.53	1.01	20.20	1.12	77.67
		(2.26)	(7.43)	(1.77)	(7.86)
5	0.65	1.05	23.28	0.74	74.93
		(2.55)	(8.41)	(1.56)	(8.83)
6	0.77	1.16	25.56	0.54	72.74
		(2.89)	(9.23)	(1.48)	(9.71)
7	0.87	1.29	27.54	0.44	70.73
		(3.22)	(9.91)	(1.50)	(10.46)
8	0.97	1.43	29.11	0.41	69.05
		(3.53)	(10.48)	(1.61)	(11.12)
9	1.07	1.57	30.38	0.43	67.63
		(3.81)	(10.95)	(1.80)	(11.67)
10	1.15	1.69	31.42	0.48	66.40
		(4.06)	(11.35)	(2.03)	(12.15)
11	1.23	1.81	32.27	0.57	65.36
		(4.27)	(11.69)	(2.31)	(12.55)
12	1.30	1.90	32.95	0.69	64.47
		(4.46)	(11.97)	(2.62)	(12.90)

Analytic standard errors are in parentheses below the estimates.

Authors: Edward N. Gamber, Frederick L. Joutz

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